MUTUAL ADJUSTMENT OF MASS FLUX AND STRATIFICATION PROFILES

Final Project

(Brian Mapes' paper and a case study of mine)

Mesoscale Convection (MPO 663)
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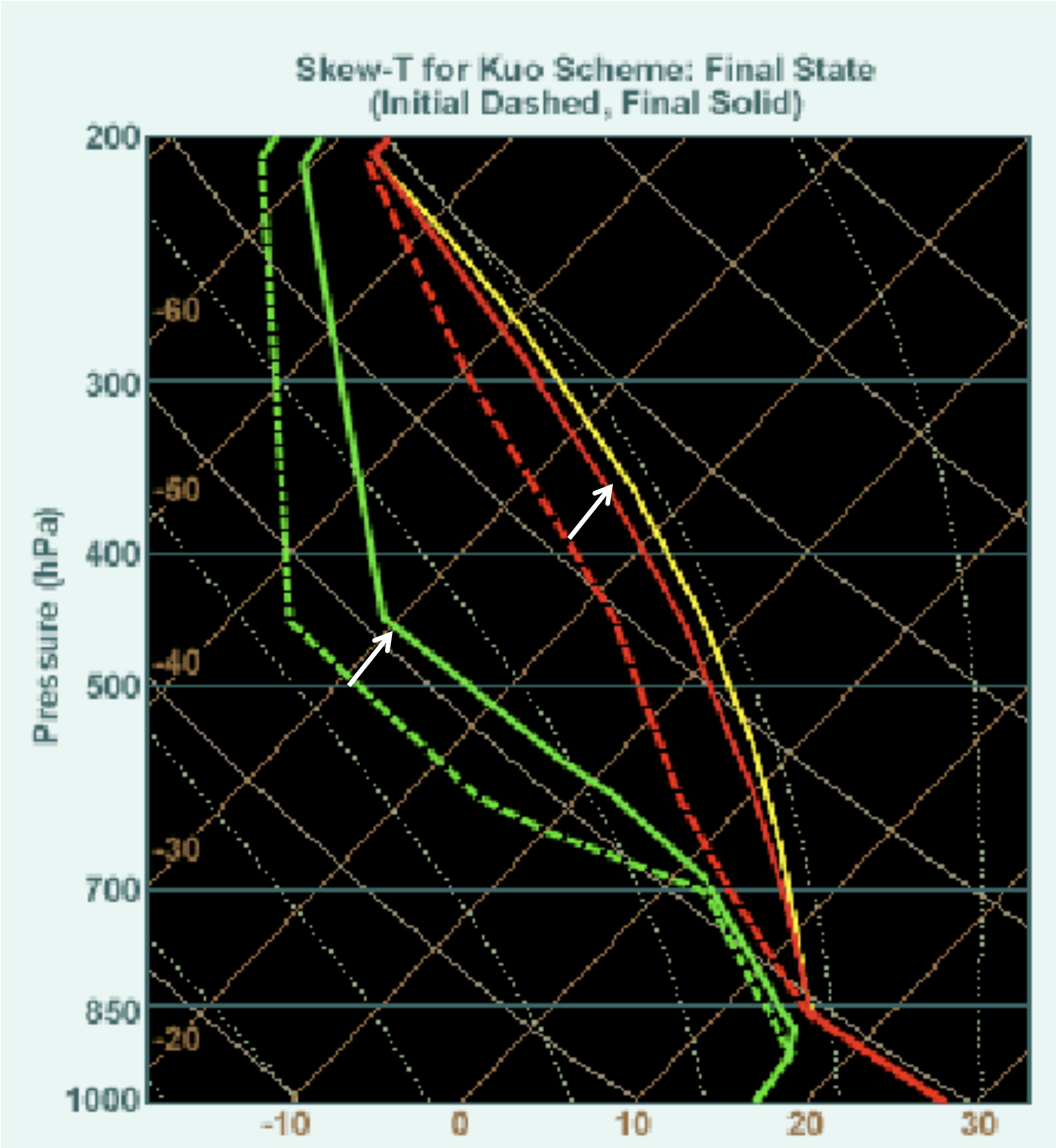
Introduction

About Cumulonimbus Dynamics and its Interaction with the Environment

- Observations indicate that deep convective heating profiles tend to oppose temperature perturbations in the environment.
- As a result, convection tends to adjust the environmental density profile toward some preferred mean state.



From COMET

Convection opposing perturbations in the environment

- The preferred stratification established by the model convection depends on the treatment of precipitation and ice processes
- And especially on the processes that determine mass flux in downdrafts*.

*A highly complex problem

Convection interaction with the ambient stratification

- Convective clouds tend to eject mass laterally into particularly strongly stratified layers of their environment.

- Penetrating convective clouds can be visualized as prising apart isentropes wherever they are pressed together, and pressing them together where they are far apart.

- So, convection heats the environment more where is it anomalously cool, and heats less where it is anomalously warm.

Divergence observations of a particular Mesoscale Convective System on Feb 6, 1993

Observations summarized:

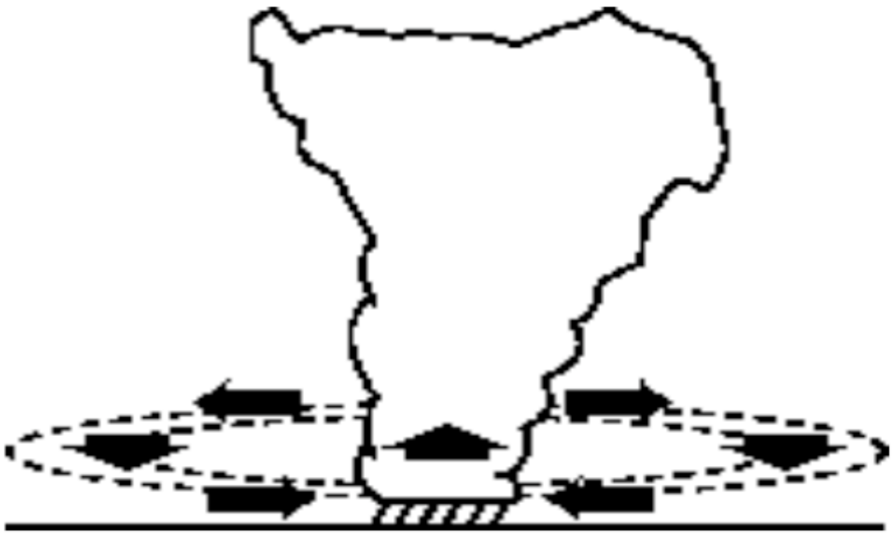


Figure 3. Schematic of observations of Feb 6 MCS, with cool anomaly (dashed) and divergence anomalies (horizontal arrows).

Convergence of mass at low levels (below the cool layer) and divergence of mass at upper levels (above the cool layer).

Is the convection opposing temperature perturbations in the environment?

Mutual Adjustment of Mass Flux and Stratification

- Within the cool layer the in-cloud mass flux is anomalously upward, it feels extra bouyancy.
- The extra upward net mass flux implies extra net condensation, and hence extra convective heating, which is expressed in the environment as extra subsidence (downward arrows).
- And note that this extra heating in the cool layer tends to oppose the temperature anomaly that created it

Figure 3. Schematic of observations of Feb 6 MCS, with cool anomaly (dashed) and divergence anomalies (horizontal arrows).

On the environment response to the convective heating

Figure 3. Schematic of observations of Feb 6 MCS, with cool anomaly (dashed) and divergence anomalies (horizontal arrows).

- This process occurs rapidly, as a gravity wave process, with characteristic velocity of up to 50 m/s.
- As a result the latent heat released in a precipitating convective cloud is quickly spread over a long area causing only slight temperature perturbations.

Modeling the problem

- A nice, clean approach: It is used a convection model of cumulonimbus dynamics (RB model), coupled to the linear dynamics of stratified flow (primitive equations model).

THE RAYMOND-BLYTH MODEL

- The RB model is based on the concept of buoyancy sorting.
- A convective cloud is idealized as an updraft parcel of air from low levels which ascends to its highest level of neutral buoyancy along some kind of moist adiabat.
- At each intervening level in the atmosphere, 9 mixing events are assumed to take place, creating mixtures of ambient and updraft air.

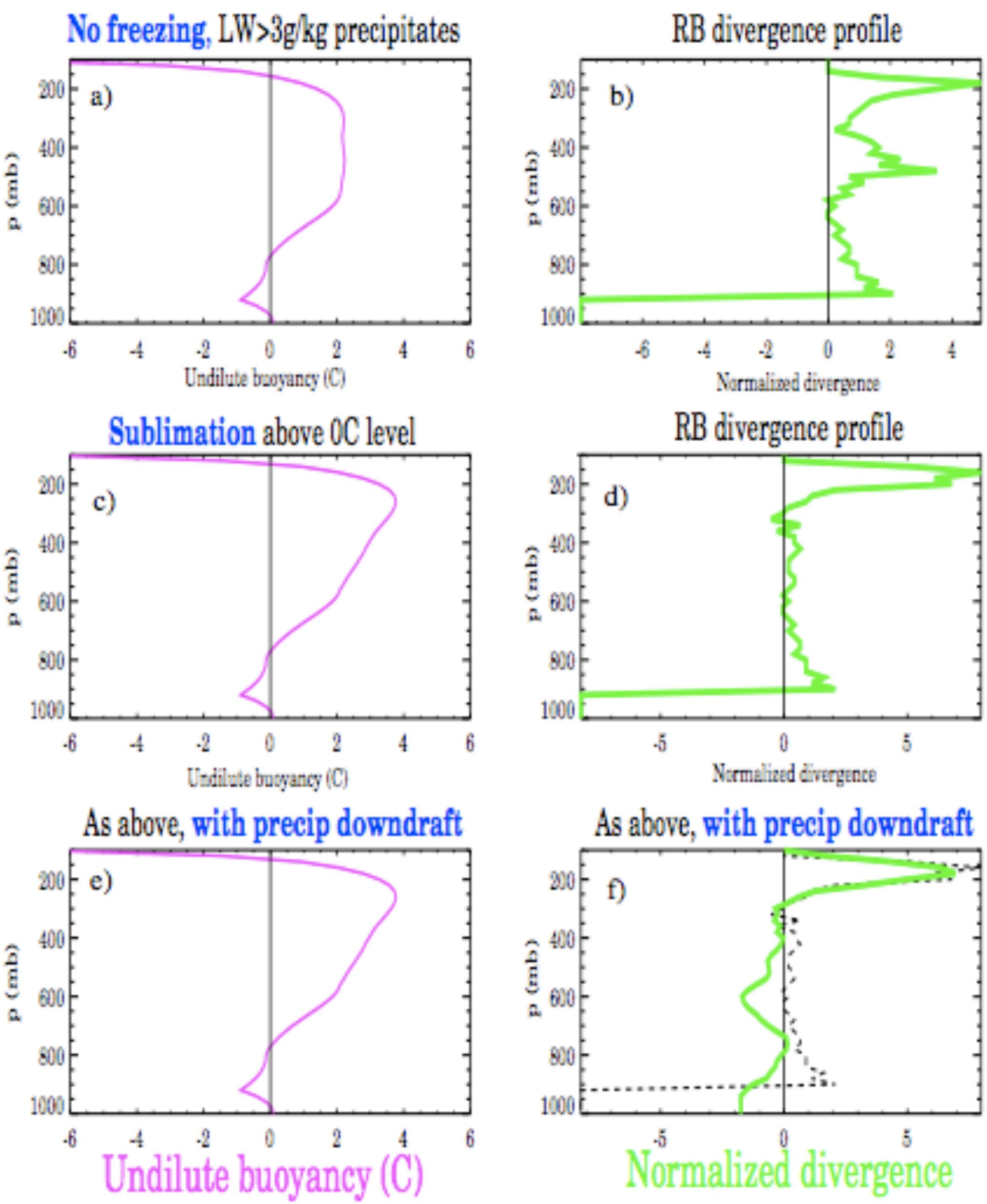


Figure 4. The Raymond-Blyth model's responses to the COARE mean sounding. Left column: undilute parcel buoyancies for different assumptions about ice and precipitation. Right column: the corresponding divergence profiles.

From an input sounding and input parcel, the RB model predicts a profile of the detrainment of neutrally buoyant air

(a diabatic divergence profile).

Figure 3. Schematic of observations of Feb 6 MCS, with cool anomaly (dashed) and divergence anomalies (horizontal arrows).

if it was not clearly said

- The RB model predicts the time-evolving diabatic divergence profile based on the time-evolving temperature field in the convective region.

- And the dynamic model (to which the RB is coupled with) predicts temperature perturbations, based on the time history of diabatic divergence.

  (As in homework 2)

THE RB+DOWNDRAFT CONVECTION'S PREFERRED STRATIFICATION

Using the more interactive RB model

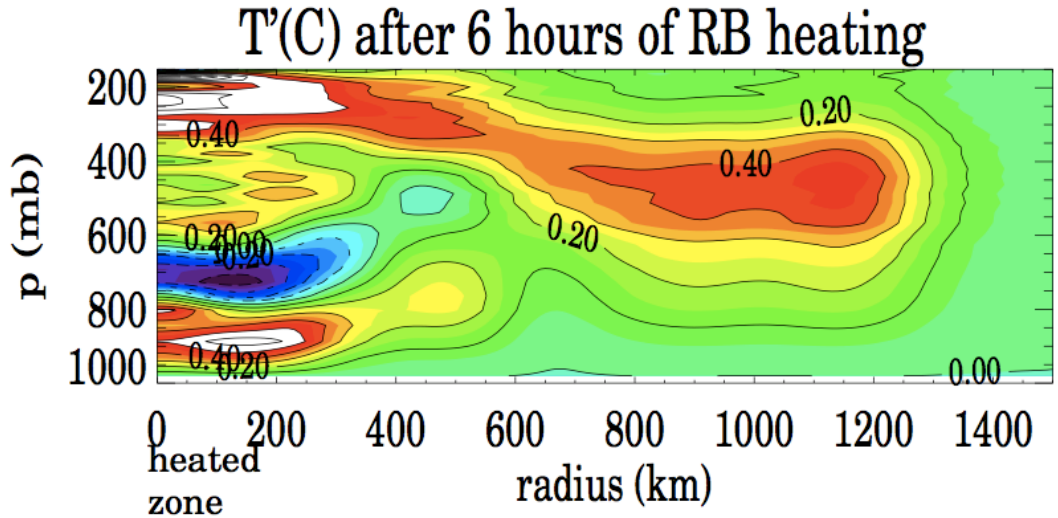
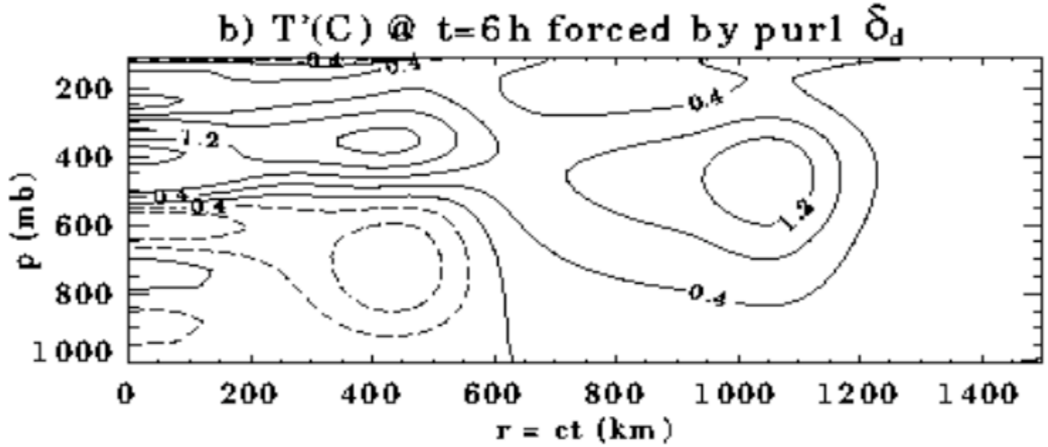


Figure 5. The temperature perturbation field after 6 hours of model convection, with specified intensity but interactively determined profile (c.f. Fig 2b).

Using the mean divergence profiles from radar observations to MCS (average of 146).

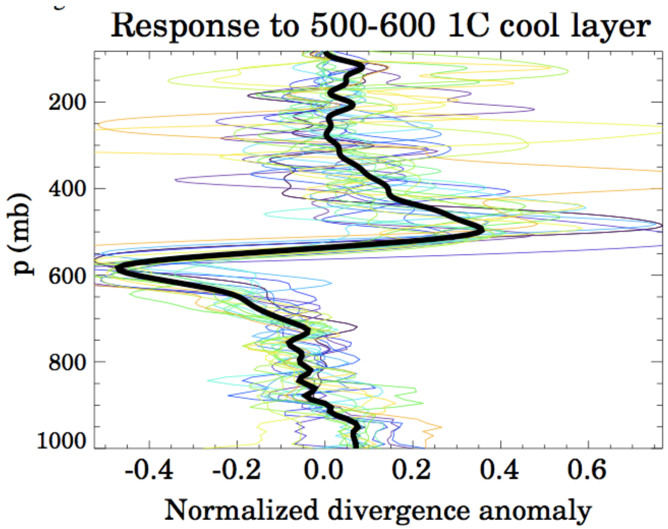
(The divergence profile was assumed to be the diabatic divergence profile, so it can be used to thermally force the circulations)



The temperature change in a linear resting model caused by 140km radius of heating

SENSITIVITY STUDIES

- It is prescribed a cool anomaly in the 500-600 mb layer (A Gaussian -1° C peak)
- The time-evolving and 6h time-mean response of the Raymond-Blythe divergence profiles to this temperature anomaly



Negative: entrainment
Possitive: detrainment

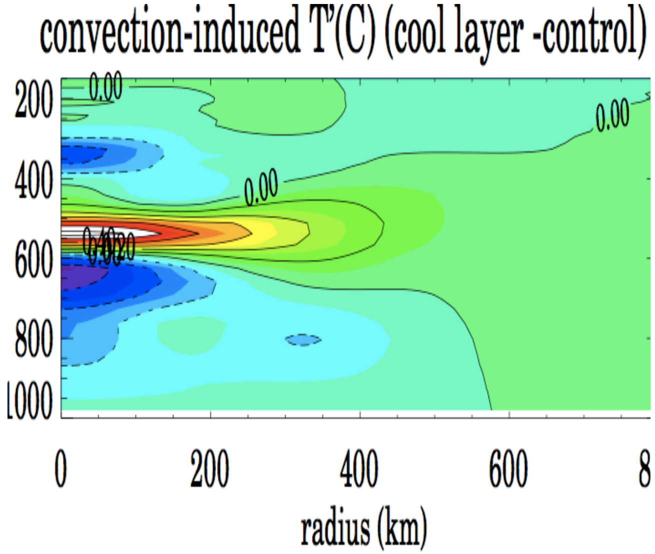
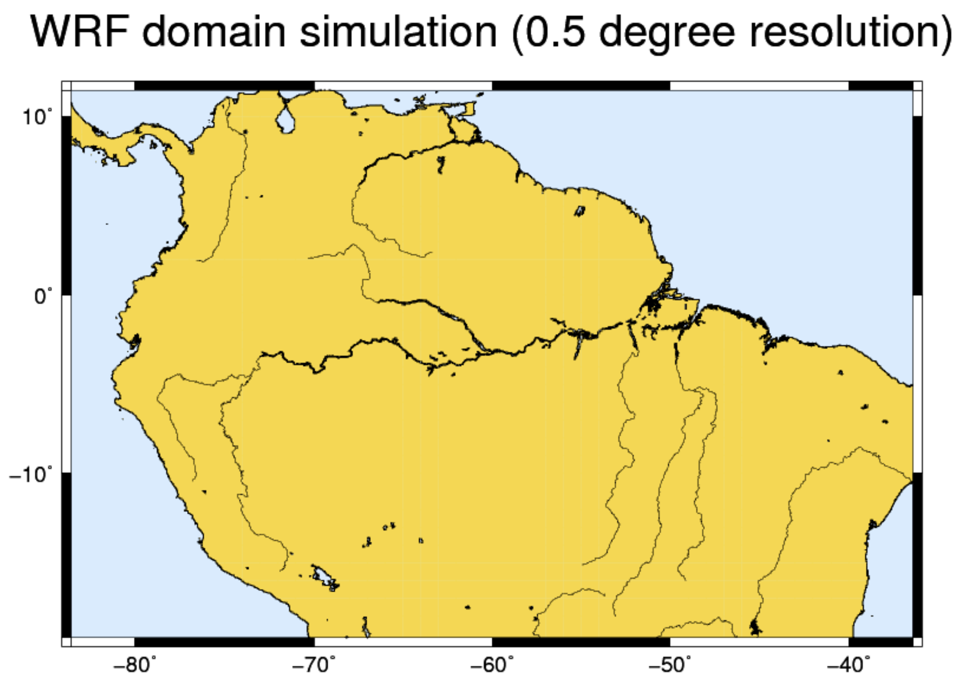


Figure 3. Schematic of observations of Feb 6 MCS, with cool anomaly (dashed) and divergence anomalies (horizontal arrows).

A case study with a more complex model

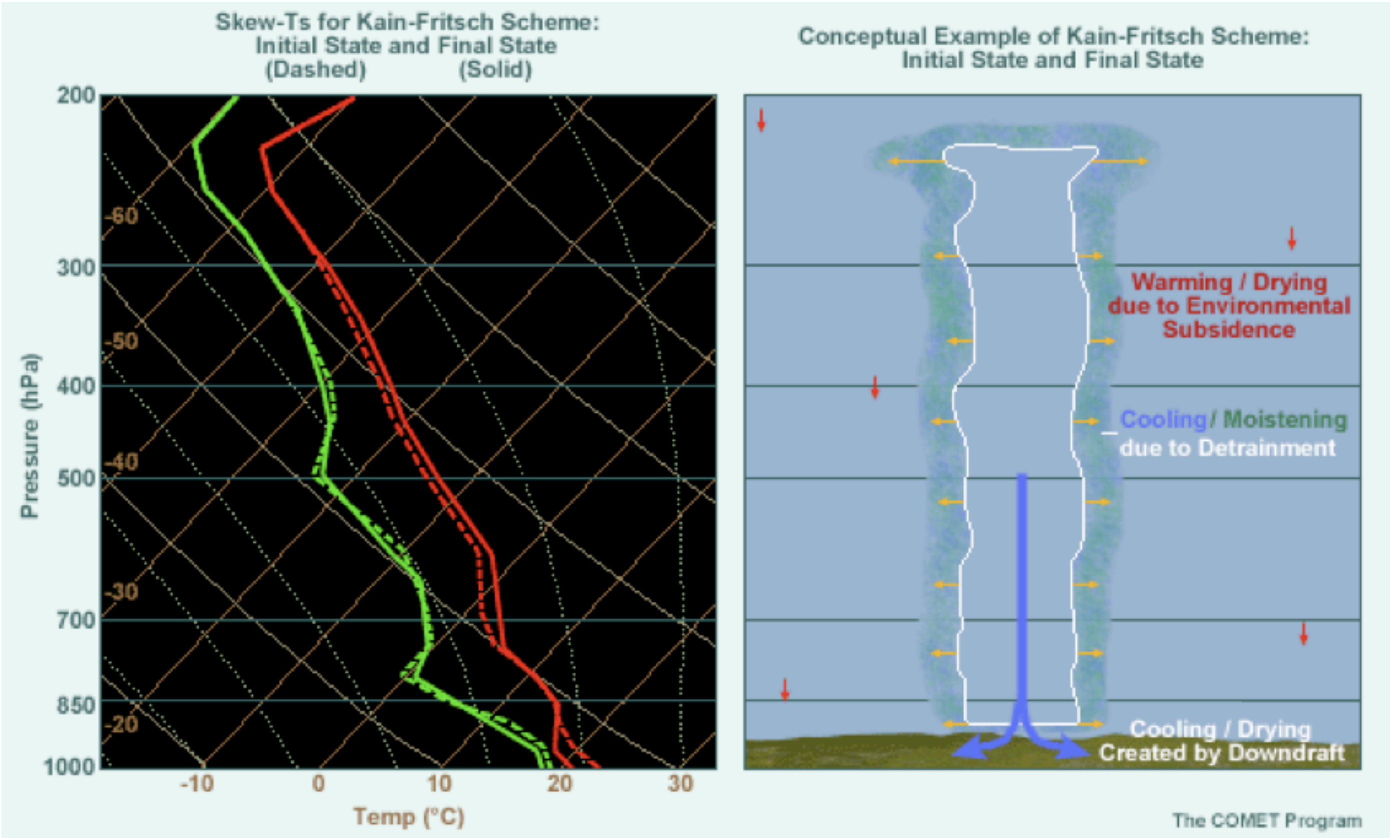
- WRF
- Resolution of ½ degree
- 1 month simulation may 2005



The Amazon region

Kain-Fritsch convection scheme

- A complex scheme designed to rearrange mass in a column so that CAPE is consumed
  Buoyancy-based.



The experiment

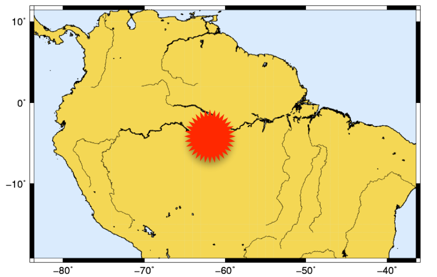
- Again, we want to show: Convective heating opposes temperature profile anomalies, tending to adjust the stratification toward its preferred version of a moist adiabat.

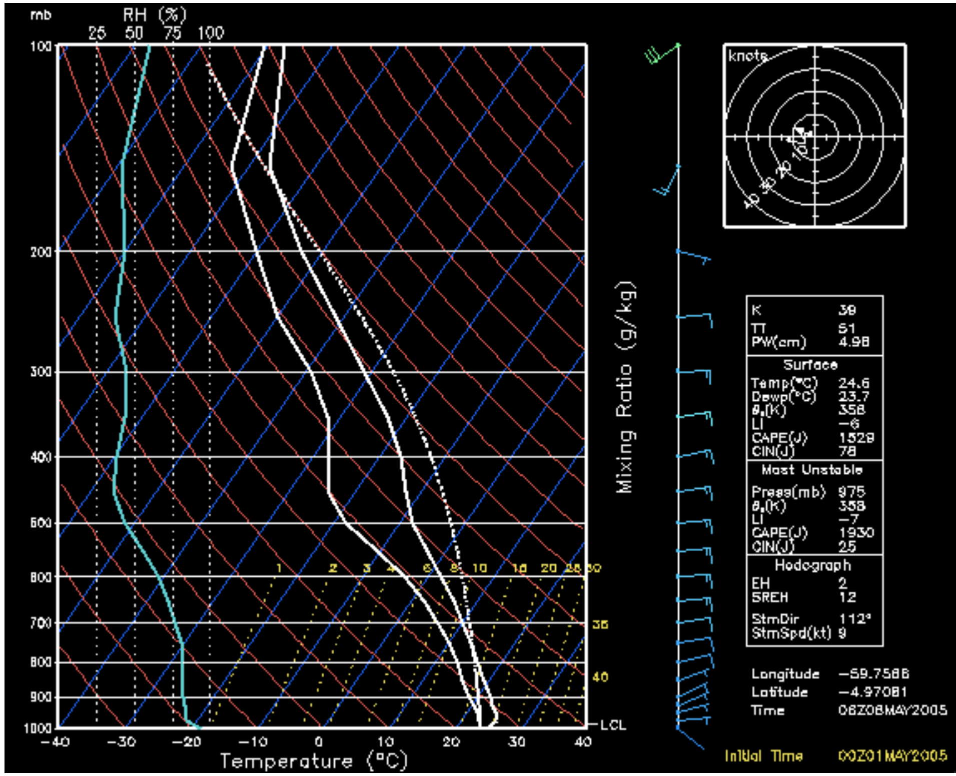
- Impose a cooling profile that is uniform throughout the domain (artificial and arbitrary).
- No horizontal gradients
- The intention is changing only the environmental Temperature (T_{env}) profile

Change in the environmental Temperature

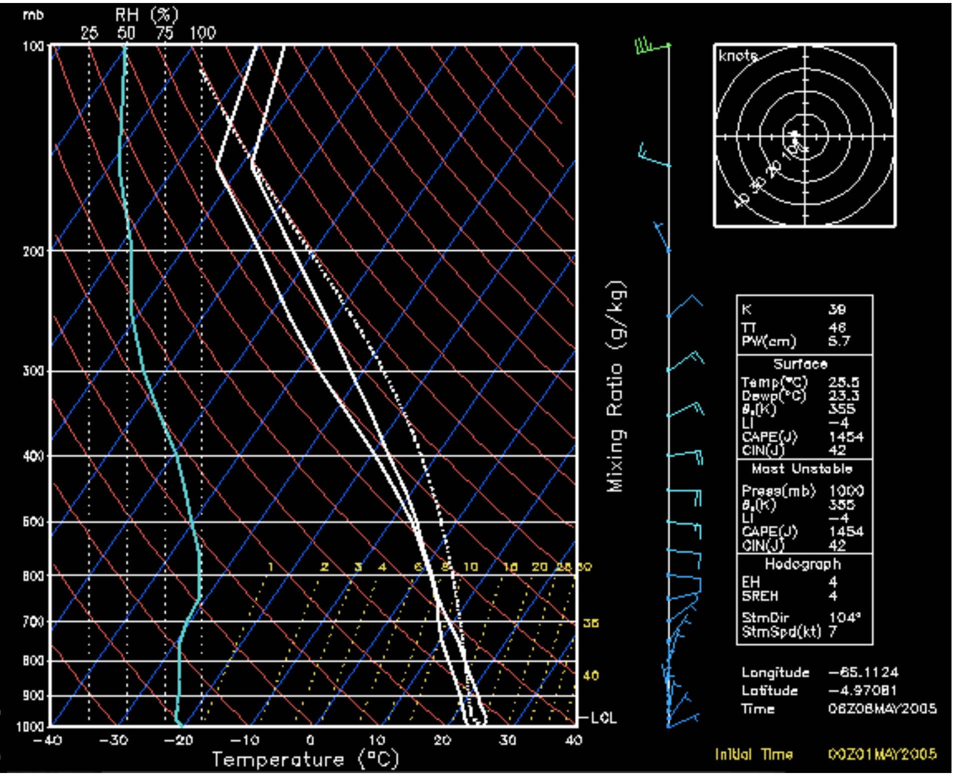
-2° K about the 500-450 mb Layer

WRF domain simulation (0.5 degree resolution)

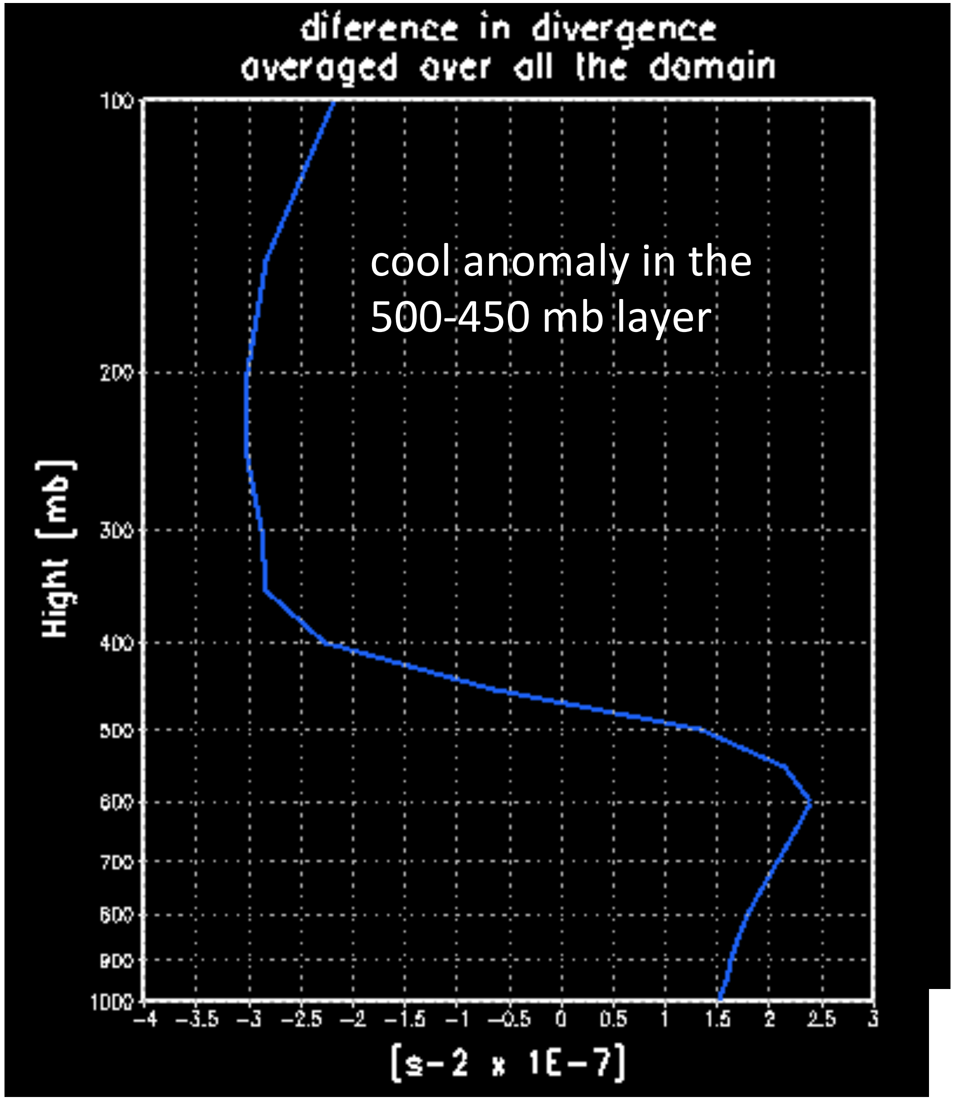




Perturbed environment after 1 day of simulation



Reference



cool anomaly in the 500-600 mb layer

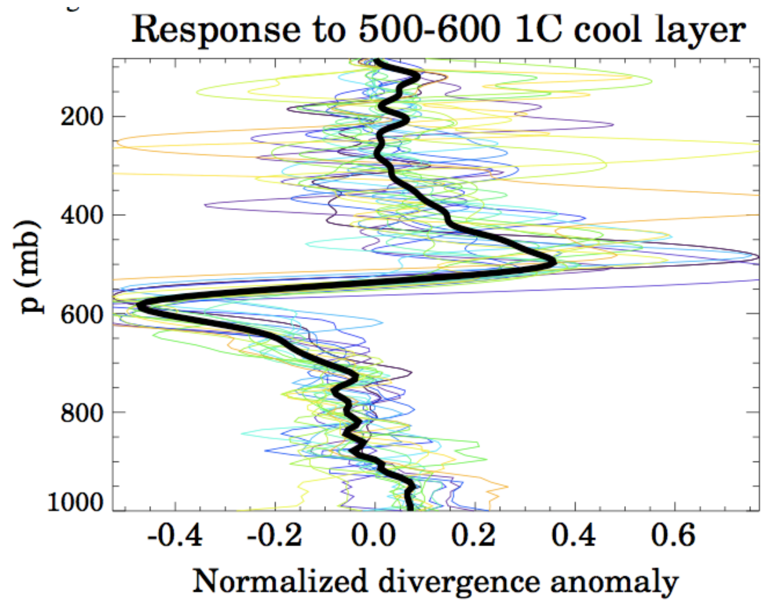
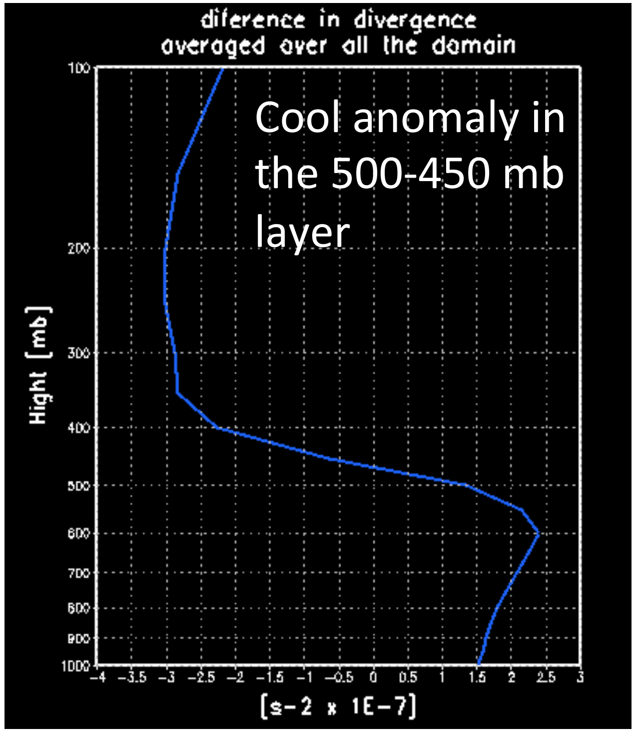
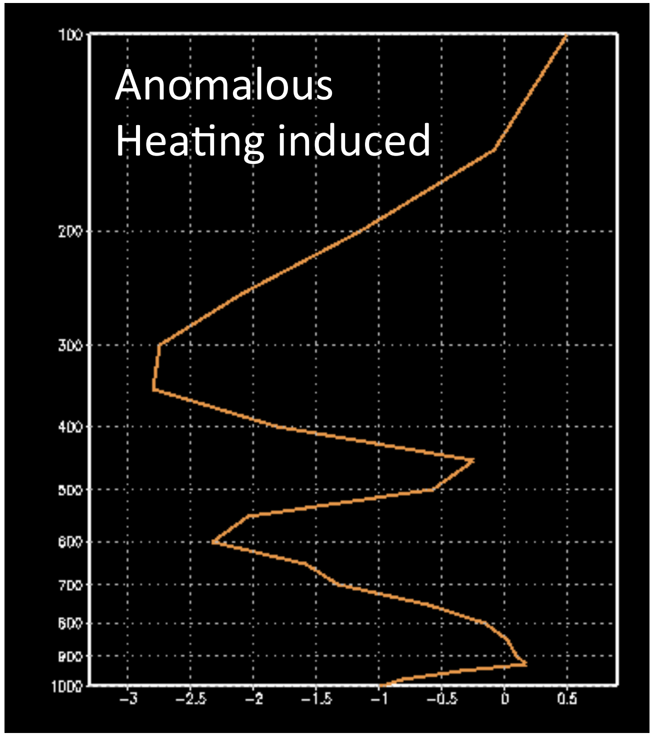
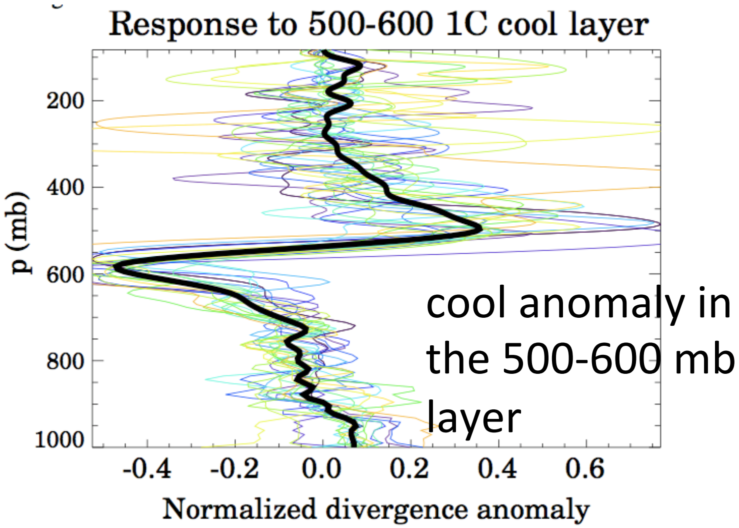
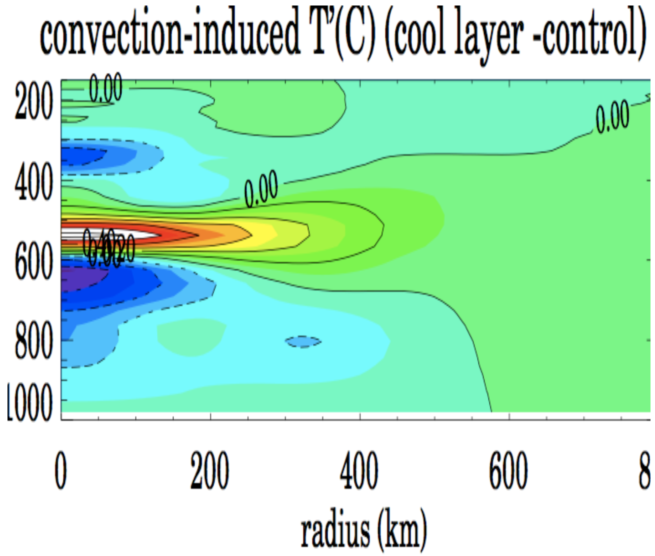


Figure 7. The anomalous divergence response of the RB cloud model, every 20 minutes for 6 hours (light lines) and mean (heavy line), to a 1C Gaussian cool anomaly in the 500-600 mb layer.


diference in divergence
averaged over all the domain
Cool anomaly in the 500-450 mb layer
Hight [mb]
[s-2 x 1E-7]
100
200
300
400
500
600
700
800
900
1000
-4 -3.5 -3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3


Anomalous Heating induced
100
200
300
400
500
600
700
800
900
1000
-3 -2.5 -2 -1.5 -1 -0.5 0 0.5

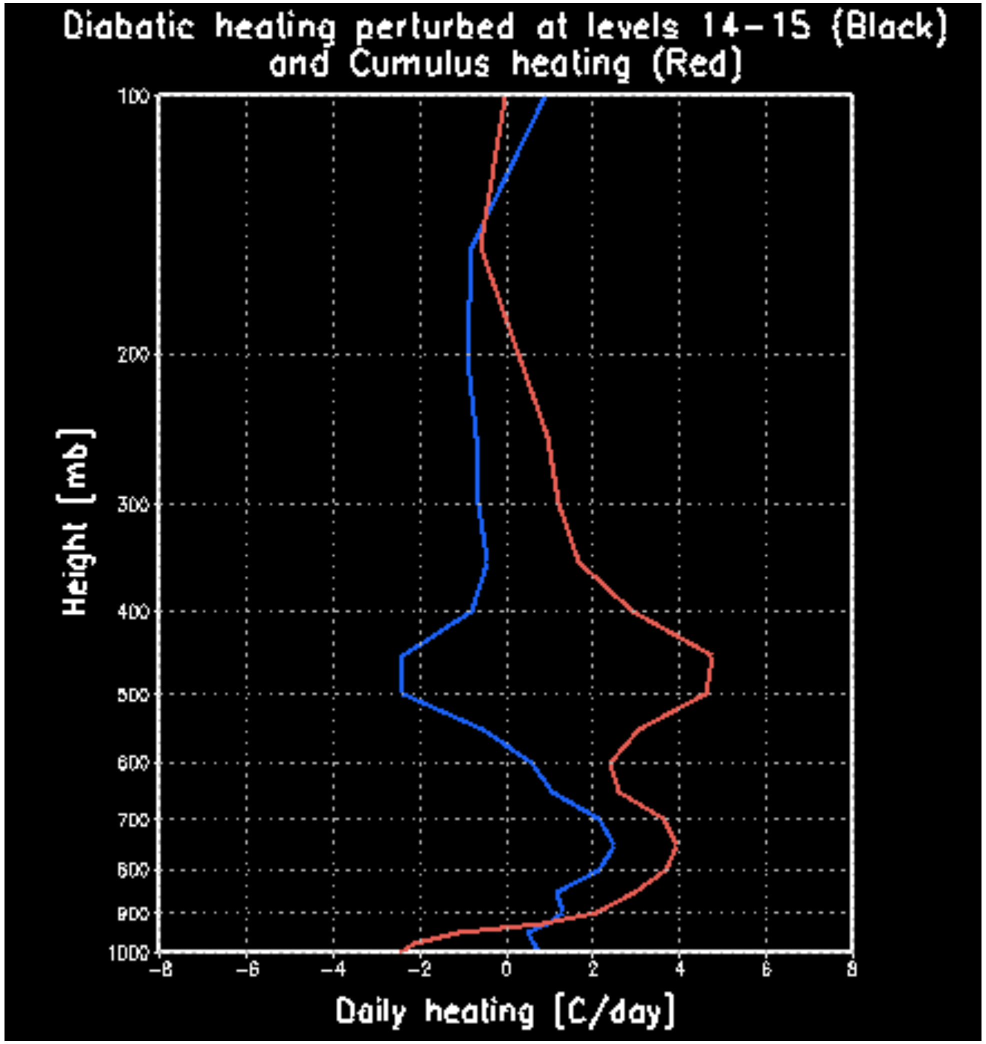

Response to 500-600 1C cool layer
p (mb)
200
400
600
800
1000
-0.4 -0.2 0.0 0.2 0.4 0.6
Normalized divergence anomaly
cool anomaly in the 500-600 mb layer


convection-induced T'(C) (cool layer -control)
0.00
0.00
0.00
200
400
600
800
1000
0
200
400
600
8
radius (km)

The cumulus Heating

- The convective heating acts to oppose the cooling layer.

- Tries to drive the T profile back toward its prefered "moist adiabat”.



Paper Conclusions

- Convective heating opposes temperature profile anomalies, tending to adjust the stratification toward its preferred version of a moist adiabat.
- The particular nature of that moist adiabat is determined by the bulk properties of updrafts (including the microphysics of freezing and precipitation within them), and of downdrafts driven by the evaporation of precipitation.
- Observations of mean stratification in convecting regions may contain useful, highly averaged information on hard-to-observe bulk parameters characterizing the ensemble of real convective clouds.
- Temperature perturbations of < 1° C are quite important in this buoyancy-sorting model, suggesting that such stratification observations should be scrutinized to this precision


Thank you!